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TIMBER MANAGEMENT OPPORTUNITIES in PENNSYLVANIA

by

Henry H. Webster

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Preface

THE Forest Survey, a major activity of the Division of Forest Economics Research, U. S. Forest Service, has the following broad objectives: (1) to inventory present supplies of timber and other forest products; (2) to ascertain timber growth rates; (3) to determine the drain on the forests through industrial and local timber use, windfall, fire, flood, and disease; (4) to determine the present requirements for timber and other forest products and their probable future trends; and (5) to correlate these findings with existing and anticipated economic conditions so that policies can be formed for effective use of land suitable for timber production.

The initial survey of the timber resources of Pennsylvania made under these auspices was completed in 1955. Statistical data on forest area, timber-inventory volumes, growth rates, and rate of cutting were presented in "Timber Resources of Pennsylvania" by Roland H. Ferguson, which was published in 1958 by the Northeastern Forest Experiment Station. Ferguson did not discuss forestry program or policy alternatives.

This report supplements Ferguson's work. It analyzes several major timber-production opportunities available to the Pennsylvania Department of Forests and Waters, the major forest-resource-managing agency in the state.

Readers wishing to examine the analysis in greater detail are referred to "An Economic Analysis of Certain Stumpage Production Alternatives in Pennsylvania", an unpublished office report available on loan from the Northeastern Forest Experiment Station.

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Contents

The Situation in Pennsylvania

THE Pennsylvania Department of Forests and Waters serves the people in managing state forest lands and in helping private owners manage their forest lands. To produce more timber from Pennsylvania forests, the Department applies many different forestry practices. But the more effort it spends in one direction, the less it can spend in others. So the Department must make choices, seeking the directions by which it can gain the greatest possible increase in timber values for the money it spends.

To help the Department find the most profitable directions, we made a study to analyze some of the timber-management opportunities that the Department has. This is a report on that study.

Although the study was directed at timber production, timber is not necessarily the only value to be gained from Pennsylvania's forests. Recreational values are also important, and they could be improved for the benefit of the people of the state. Water values are likewise important, and they too could be improved. But in the study we were concerned with producing more and better timber.

Commercial forests occupy 15 million acres in Pennsylvania--53 percent of the state's land area. They supply more than three-fourths of the timber processed by timber-based industries in the state. These forest industries employ nearly 70,000 workers, pay wages and salaries totaling $250 million annually, and by manufacture add values totaling $425 million each year (Ferguson, 1958).

Impressive as these figures are, an expanded volume of timber available for use would mean even greater benefits for Pennsylvanians, and these benefits would be for all Pennsylvanians--even those many people who have no direct connection with the forests. More timber means more wood products for consumers--more lumber, more paper, more building board, and more paper containers, to name just a few. Also, more timber would increase the income received by those who make a living processing these products. And it would increase the incomes of those who sell timber from their woods.

How could Pennsylvanians increase the volume of timber available? They could do it in two ways. First, they could increase timber production by their own efforts, by managing more intensively the forest land that they individually own. Second, they could increase timber production by their joint efforts, operating through the state government to manage State Forests and to assist private owners in managing their forests.

Joint efforts are frequently used for several reasons. In the first place, a vast majority of Pennsylvanians do not own forest land. Then too, some of the benefits of increased production are not received by current owners because of the long time required to grow mature timber. And some owners may find it difficult or inconvenient to learn even a few forestry techniques.

The people of Pennsylvania have already taken joint action to increase timber production. They have established the Pennsylvania Department of Forests and Waters as their agent. Among other duties, the Department manages nearly 2 million acres of State Forests and provides technical assistance to some of the 300,000 owners of private forests in the state (U.S. Forest Service, 1958). In recent years, the Department has become increasingly active in both of these phases of its timber-production program.

The Basic Problem

Within its mandate to manage State Forests and to assist owners of private forest land, the Department of Forests and Waters has considerable discretion concerning the technical details of forest management. As people want more timber produced, the Department can devote more effort to a variety of measures. It can intensify fire protection. It can intensify and broaden the scope of insect and disease control. It can enlarge its planting program. It can increase efforts to apply stand-improvement measures such as thinning, cleaning, cull-tree removal, and pruning. It can step up educational efforts to insure that stands are not harvested prematurely. And so on. But budget limits dictate that more effort in one direction means less effort in another.

In short, the Department of Forests and Waters is faced with a series of decisions or choices. It must decide how much effort to devote to each of these ways of increasing timber production. To be specific, suppose the Depart-

ment were to receive an additional appropriation of, say, $4 million for each of the next 5 years for timber production. Foresters in the Department would have to decide how to spend this money, how it should be allocated among the various forestry practices. And they would have to do so with whatever information were available, even though it were not all that might ideally be used as a basis for decision.

The details of deriving an answer to this question are complicated, but the concept is rather simple. All can agree that the Department of Forests and Waters can perform its function most efficiently by first taking advantage of those opportunities that offer the largest returns in relation to costs.[1] By doing this, additional timber will be produced at lowest cost and the greatest possible increase in timber values will be obtained with any increase in available funds. In working toward this objective in its timber-management programs, the Department of Forests and Waters may rank its opportunities from best to poorest in terms of cost of additional timber produced, and then take advantage of them in this order.

However, in actually making these comparisons, complications arise. It is often difficult to determine the costs and the returns from forestry practices. The study reported in this paper was designed to overcome some of these difficulties, and so to assist the Department of Forests and Waters in choosing effectively among its opportunities.

Not all the data needed were available from formal studies. The best judgment estimates of experienced foresters were used at many points. This was done because lack of completed, long-term studies does not relieve decision-makers of the necessity of choosing among alternate courses of action.

COMPARISONS MADE

Many forestry practices could be included in a comprehensive comparison of timber-management opportunities. Those already mentioned are a sample. For practical reasons, the number and variety included in any one study have to be restricted. In this study, we compared three sets of the most promising practices, namely: (1) planting of softwoods

[1]For further discussion of this general principle as it applied to forest management of all types, see Stoltenberg, Carl H. An investment-opportunity approach to forestry programming. Jour. Forestry 57: 547-550. 1959.

(white pine and Norway spruce) on open or lightly stocked forest land (fig. 1); (2) cleaning and cull-tree removal in hardwood seedling-and-sapling stands (fig. 2); and (3) thinning in hardwood-poletimber stands (fig. 3).

Figure 1.--*A good example of a softwood planting (white pine) on open land.*

These practices were suggested by several considerations. First, the allocation of effort between softwoods and hardwoods is a major choice in timber management. And in Pennsylvania, this choice is largely one of planting softwoods or managing existing hardwood stands, because softwood forest types occupy less than 5 percent of the commercial forest land area (Ferguson, 1958). Management efforts could be concentrated in immature hardwood stands or in those approaching maturity. But working in the younger stands permits a greater improvement in volume and value of the eventual stand yield, so we designed this study to evaluate alternatives appropriate to hardwood seedling-and-sapling and poletimber stands.

Management in seedling-and-sapling stands can begin with cleaning to improve species composition and timber quality, and with cull-tree removal to increase total output. In poletimber stands, a logical first step is thinning to shorten the rotation and to improve species composition and timber quality.

Figure 2.--*A hardwood seedling-and-sapling stand where a defective cull has been girdled to release saplings.*

To compare opportunities associated with these forestry practices, four types of information are needed. The first is a classification of existing stands according to their suitability for each of the treatments being compared. Area estimates for each treatment class are a part of this classification. The second is an estimate of the cost of applying each treatment in each of the various stand conditions encountered. The third type of information needed is an estimate of the output response of various stands to each treatment. And the fourth is a system for converting to a common basis the output responses of various stands. Dollar values are used as a common denominator so that comparisons can be made of the relative benefits of increased production of, say, spruce pulpwood, low-quality beech, and veneer-quality black cherry.

So much for the problem analyzed in this study and for the types of information needed. Now to compile this information. And to make it easier for the reader to follow the analysis of the various timber-management opportunities, figure 4 (in the center fold) presents a "road map" of the general steps and directions taken.

Compiling the Basic Data

The data used in this study to compare timber-management opportunities can be most readily compiled by considering separately each of the four types of information needed: (1) treatment classes and treatment-class-area estimates, (2) treatment costs, (3) output responses, and (4) a system for converting output responses to a common basis.

But first, we must emphasize one point. Throughout this study, we are dealing with *additional output* that can be produced by applying *additional forestry practices*. In comparing planting, cleaning and cull-tree removal, and thinning, many other aspects of present forestry programs are taken as they now exist. Thus we assume for analytical purposes that the following costs are fixed: the cost of protecting forest land against fire, insects, and diseases; the overhead or administrative costs of public land ownership and management; and the overhead or administrative costs of public assistance to private forest landowners.

TREATMENT CLASSES AND AREA ESTIMATES

In this study we recognized 11 treatment classes for planting, 5 treatment classes for cleaning and cull tree removal, and 7 treatment classes for thinning. In each case, the classes were defined in terms of site productivity and forest type or site preparation.

The treatment classes for planting were specified by first recognizing differences in the amount of site preparation required, and then further separating these classes into those based on site-productivity. The treatment classes for cleaning and cull-tree removal and for thinning were specified by recognizing (1) that the northern hardwood and mixed-oak types contain the most productive seedling-and-sapling stands in Pennsylvania, (2) that these types and the cove hardwood type contain the most productive poletimber stands, and (3) that a minimum stocking of at least 40 percent is required before any cultural measures are practical. On the basis of site productivity, these classes were also subdivided to give a reasonable compromise between a manageable number of classes and constant costs and returns within classes.

Plantable area as reported in The Timber Resource Review (U. S. Forest Service, 1958) was the starting point for area estimates in terms of site preparation required. We separated this 1.1 million plantable acres into scrub-oak land, forest land less than 10 percent stocked, and open land; we used Forest Survey area estimates for the first two categories, obtaining open land area as a residual. Scrub-oak land was further broken down in terms of appropriate site-preparation methods (root-rate vs. mist-blower) based on experiments at the Delaware-Lehigh Experimental Forest. Finally, Forest Survey ownership data were used to break "forest land less than 10 percent stocked" into that suitable for site preparation by aerial spraying and that suitable only for site preparation by ground methods. We assumed (1) that site preparation on all public land and on private land in holdings 5,000 acres and larger would be by aerial methods, (2) that site preparation on smaller private holdings would be by ground methods, and (3) that plantable area is divided between the two classes in the same proportion as forest area.

Forest Survey data were used to determine area for the various treatment classes as defined in terms of forest type. Estimates for seedling-and-sapling stands and poletimber stands in the northern hardwood, mixed oak, and cove hardwood type-groups were used after making appropriate reductions for areas less than 40 percent stocked.

Estimates of treatment-class area by site class were derived from the distribution of site classes by forest types on State Forest land. This distribution was applied directly to the previous area estimates for seedling-and-sapling and poletimber stands to obtain area for each of the treatment classes for cleaning and cull-tree removal and for thinning. Similar area estimates were made for treatment classes for planting on forest land less than 10 percent stocked. This was done by combining the site-class forest-type distribution with Forest Survey data, breaking down the less-than-10-percent-stocking class by forest types. Open-land area by site-classes was estimated by directly applying the proportional breakdown derived for forest land less than 10 percent stocked.

TREATMENT COSTS

We next estimated treatment costs, once treatment classes had been specified and area determined for each. These cost estimates were synthesized from numerous studies and judgment estimates of each cost element.

Planting and Site-Preparation Costs

Planting-stock production, site preparation, and field planting were the cost elements recognized in the case of planting. Planting-stock costs were estimated by trying to visualize the effects of progressively expanding production at the nurseries now operated by the Pennsylvania Department of Forests and Waters. The following elements were considered: production cost in established seedbeds; direct labor, materials, and land-acquisition costs of enlarging seedbeds; cost of buildings to service additional seedbed area; and salary costs of additional nursery staff.

Site preparation and field planting costs were built up from estimates of the required equipment, labor, supervision, and material (i.e., silvicide used in site preparation). For example, the cost of root-raking scrub oak land was taken from estimates of the time required to lay out and supervise the job, equipment time required to perform the job, and applicable equipment and supervisory wage rates. However, where operations are commonly carried out on a contract basis, the price quoted for the completed job was used. Thus where machine planting was feasible, the cost of field planting was based on a flat $20 per thousand trees.

Figure 3. --*A hardwood-poletimber stand which was thinned to hasten the natural thinning that occurs in such woodlots.*

Cost estimates for cleaning and cull-tree removal and for thinning were based on poisoning with sodium arsenite of trees of specified diameter distributions. These costs were calculated by using equations relating labor-time and chemical used to the sum of the diameters of the trees poisoned (Curtis, 1956).[2]

The number and type of trees to be removed from a given stand in a cleaning and cull-tree removal operation or in a thinning can be determined, of course, only after an on-the-ground inspection. In any case, the emphasis in cleaning and cull-tree removal in hardwood seedling-and-sapling-stands will be on maintaining an adequate number of stems in the residual stand, on getting rid of trees that are not merchantable now or in the future, and on eliminating trees of undesirable species where it is possible to favor more desirable species. In thinning hardwood pole-timber stands, the objectives are much the same, except that less attention is paid to the seedling-and-sapling component since the main stand is already past this stage.

Operating within these guidelines, we estimated the diameter distributions of trees to be removed in cleaning and cull-tree-removal operations and in thinnings by working with Forest Survey stand tables for each forest type and stand size and assuming the removal of cull trees, low-quality "hold-over-trees" from former stands, non-commercial species, etc.

To be specific, we assumed that the following kinds of trees would be removed:

<u>In cleaning and cull-tree removal</u>

1. All trees 2 inches and larger d.b.h. classified by the Forest Survey as cull trees.

2. Other low-value "hold-over trees" from former stands 12 inches and larger d.b.h.

3. All hickory, elm, aspen, and "non-commercial species" (as defined by Forest Survey) 2 inches and larger d.b.h.

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[2]Carvell, Kenneth L. The use of chemicals in controlling forest stand composition in the Duke Forest. Unpublished doctoral dissertation, Duke Univ., 1953.

4. One-half of the red maple and beech in each diameter class from 2 to 10 inches.

In thinning

1. All cull trees 5 inches and larger d.b.h.

2. All hickory, elm, aspen, and non-commercial species 5 inches and larger d.b.h.

3. One-half of the red maple and beech in each diameter class 5 inches and larger.

OUTPUT RESPONSES

How will planting, cleaning and cull-tree removal, and thinning change the timber output of stands harvested at appropriate ages? Answering this question was our next step once we had determined area and treatment cost for each treatment class.

A management program beginning with planting on open or lightly stocked forest land eventually produces mature timber where otherwise there would be little or none. Therefore the entire output is a result of management. Output response can be specified in terms of the most likely rotation and the volume and quality of the timber produced during this rotation.

But when management begins with stand-improvement measures, the situation is more complex; then a stand already exists, and considerable timber would be produced without any sort of management. Here only change in output is relevant.

To specify the response to cleaning and cull-tree removal and to thinning, we must first define these practices. Cleaning and cull-tree removal, while most efficiently carried out in a single operation, are really two separate practices performed in young stands not yet past the sapling stage. (But for the purposes of this study they are grouped as a single practice.) Cleaning, a practice which removes some young trees from the stand, frees the remaining young trees from their competition. Cull-tree removal frees young trees from overtopping by defective trees that are the remnants of a former stand. On the other hand, thinnings are partial cuts first made in poletimber stands to hasten the natural thinning-out that occurs as stands grow older.

In line with these definitions, we recognized the output responses listed in table 1. As indicated, cleaning

and cull-tree removal directly improve species composition and timber quality, and also increase the total volume of merchantable timber per acre. They are only a first step, however. With management begun, seedling-and-sapling stands will probably be thinned subsequently. Therefore a management program beginning with cleaning and cull-tree removal will also reduce the time required for stands to reach maturity. When management begins with thinning in poletimber stands, the responses are similar except that volume per acre is not increased; the time lost while cull trees continue to occupy a part of the stand cannot be recovered. In contrast, the other responses are reduced but not eliminated.

Table 1.--Effects of timber-stand-improvement measures on stumpage output in hardwood stands

Timber-stand-improvement measure	Effect on--			
	Gross volume	Species composition	Quality within species groups	Years required to reach maturity
Cleaning	None	Improved	Improved	None
Cull-tree removal	Increased	None	None	None
Thinning	None	Improved	Improved	Decreased

Once we had specified the output responses in qualitative terms, our remaining task was to quantify these responses. For example, it remained for us to estimate the volume of white pine sawtimber produced over an 80-year rotation on Site 1, and also to establish how much particular kinds of management programs in particular kinds of hardwood stands will affect species composition, timber quality, time to reach maturity, and so forth. True, this is a rather large step, especially since we sometimes lack full knowledge of stand response to specific forestry practices. Nevertheless, it is absolutely necessary to quantify output responses if we are to compare timber management opportunity objectively. And, in any case, the best we can ever do is to act on the best information available--and at the same time concentrate research efforts on improving that information.

Output responses can be quantified most easily by considering separately gross volume at harvest, losses to destructive agents, species composition, and timber quality. In the case of planting, one estimate at each stage for each

treatment class was sufficient. Two estimates--one for unmanaged stands and the other for managed stands--were required for each treatment class for cleaning and cull-tree removal and for each treatment class for thinning.

Gross volume at harvest.--We obtained gross volumes in unmanaged stands from appropriate yield tables (Defler, 1937,[3] as modified by Hough, 1944;[4] McIntyre, 1933; McCarthy, 1933; Hummel and Christie, 1953, as modified by Marty, 1957;[5] the Lake States Forest Experiment Station, 1957;[6] and Schnur, 1937). These yields were posted after estimates of site index, stocking, and rotation had been made for each treatment class. Site indices were obtained by relating growth rates implicit in the yield tables to growth rates for particular forest types on the site classes used by the Pennsylvania Department of Forests and Waters. Stocking percentages and rotations were based on judgment estimates of research foresters who know Pennsylvania conditions.

Management in hardwood stands will change the rotation, and hence the date of output; but it will not change the volume, except in the case of cull-tree removal. Here, the removal of culls "purchases" the area now occupied by them. We measured the effect of cull-tree removal on volume by estimating the crown area of trees poisoned (Hough, 1935). With rotations ranging from 80 to 100 years in unmanaged stands, a reduction of 20 years might be brought about when management is begun in the seedling-and-sapling stage (age 10 to 15 years). And it is reasonable to expect a reduction of 10 years when management is begun later in the poletimber stage (age 30 to 40 years).

Losses to destructive agents.--Next, we made loss adjustments for managed and unmanaged stands by separately estimating losses to fire, to insects, to diseases, and to planting failures, and then aggregating these losses to obtain net-output/gross-output ratios. These ratios reduced the yield-table figures to estimates of net output.

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[3]Defler, Sam E. Black cherry: characteristics, germination, growth and yield. Unpublished master's thesis. N.Y. State Coll. Forestry. 1937.

[4]Hough, A. F. Estimated growth, yield, and reserved growing stock in Allegheny hardwood stands under various methods of silviculture. Unpublished office report. Allegheny Forest Expt. Sta. 1944.

[5]Marty, Robert J. Office report on forest management possibilities on idle land in Potter County, Pennsylvania. Unpublished office report. Northeast. Forest Expt. Sta. 1957.

[6]Lake States Forest Experiment Station. Yield tables for use in a study of the economics of eastern white pine production. Unpublished office report. 1957.

Losses to insects, diseases, and planting failures were based on the judgment estimates of research foresters. Fire losses were estimated by calculating the probability of a killing fire during the present rotation. Two types of fire data were used: (1) the annual probability of burning (as estimated from area-burned data provided by the Department of Forests and Waters); and (2) the relationship between area burned and area affected by killing fire for pine plantations, for spruce plantations, and for hardwood stands in each of several specified age classes (based on judgment estimates by Wayne G. Banks, formerly forest fire researcher at the Northeastern Forest Experiment Station).

Calculation of the probability of no killing fire in each of the three kinds of stands, using these data, involved two steps. In the first step, the probability of no-killing-fire occurring during the time the stand will be in each of the specified age-classes was calculated as follows:

$$K = (1 - bp)^n$$

where

K = probability of no killing fire during the time the stand will be in the specified age class

b = average annual probability of burning

p = ratio of area affected by killing fire to area burned for the specified age-class

n = number of years the stand will be in the specified age class

In the second step, probability of no killing fire during the entire rotation was calculated by multiplying together all of the probabilities calculated in the first step. The probability of no killing fire was then subtracted from 1 to obtain the probability of killing fire.

So much for gross volumes at harvest and losses to destructive agents. Now to species composition and timber quality.

Species composition and timber quality.--Without special management measures, presently immature hardwood stands are likely to duplicate (within practical limits) the existing Pennsylvania sawtimber resource in terms of species composition and timber quality. Therefore we estimated these output characteristics for unmanaged stands directly from Forest Survey species breakdowns for the northern hardwood, mixed oak, and cove hardwood types, and from Forest Survey log-grade breakdowns within species.

Species composition in stands where management begins with cleaning and cull-tree removal during the seedling-and-sapling stage was estimated by applying the following practical assumptions to the species breakdowns for unmanaged stands: (1) a three-fourths reduction in the proportion of output in such relatively low-value species as beech, red maple, elm, and aspen, with (2) the corresponding increase concentrated on sugar maple (and to a lesser extent black cherry) in northern hardwood stands, on red oak and white oak in oak stands, and on yellow-poplar in cove hardwood stands.

Log-grade breakdowns in stands first managed in the seedling-and-sapling stage were derived by estimating for each of the favored species (1) the average number of merchantable logs per crop tree at the final harvest and (2) the average proportions of crop trees with butt logs of various grades, and then applying (3) data relating proportions of tree volume (by log grades) to the grade of the butt log and the number of logs.[7] The calculations had this form:

$$\begin{array}{l}\text{Log grade}\\\text{breakdowns}\\\text{for favored}\\\text{species}\end{array} = \left(\begin{array}{l}\text{Proportion of crop}\\\text{trees with grade}\\\text{1 butt log}\end{array} \times \begin{array}{l}\text{Log grade breakdown for}\\\text{trees with grade 1 butt}\\\text{log and number of logs}\\\text{estimated in (1) above}\end{array}\right)$$

$$+\left(\begin{array}{l}\text{proportion of}\\\text{crop trees with}\\\text{grade 2 butt}\\\text{log}\end{array} \times \begin{array}{l}\text{Log grade breakdown for}\\\text{trees with grade 2 butt}\\\text{log and number of logs}\\\text{estimated in (1) above}\end{array}\right) + \ldots$$

Opportunities to improve both species composition and timber quality are reduced when management is not begun until the stand reaches the poletimber stage. Probably less is lost in terms of quality than in terms of species composition; relatively poor trees can still be removed in thinning, while many trees of valuable species (such as black cherry and yellow-poplar) may have already succumbed to competition. It is reasonable to assume improvement in species composition and log-grade breakdowns one-half and two-thirds as great, respectively, as in stands first managed in the seedling-and-sapling stage.

On the other hand, timber quality in pine plantations is not likely to be a great deal better than that in natural pine stands because there will probably be little pruning on most areas planted in a large-scale program. Pruning is particularly unlikely on privately-owned land; to private owners planting simply appears to be more attractive than

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[7] These data were developed at the Northeastern Forest Experiment Station's Elkins Research Center, Elkins, W. Va.

subsequent management measures. For this reason, quality was estimated from the log-grade breakdown for the existing pine sawtimber resource in Pennsylvania, and only a small and essentially arbitrary upward adjustment was made.

In one sense, species composition is no issue in plantations since they are virtually pure stands. Both cost and output estimates for pine and spruce plantations were averaged, but pine was weighted two-thirds and spruce one-third. Recent planting of the two species in Pennsylvania has been in roughly these proportions and seems likely to continue so even with a considerable expansion in the state's planting program.

Once we had quantitatively specified the output responses for all of the treatment classes, our next step was to bring this information together as shown in table 2. We compiled one such output table for each treatment class for planting, and two for each treatment class for cleaning and cull-tree removal and thinning--one for managed stands and the other for unmanaged stands. To go farther in comparing costs and outputs, it was necessary for us to convert all outputs to a common basis. Dollar values were used as a common denominator. Therefore, we next developed stumpage-value relatives.

CONVERTING OUTPUTS TO A COMMON BASIS

Outputs in softwood plantations and in managed and unmanaged hardwood stands were specified in terms of volume per acre, harvest date (rotation minus present age), species composition, and timber quality (table 2). This information was the raw material for comparisons, but in this form we could not compare the outputs directly with each other or with the costs of the forestry practices carried out. However, we made outputs comparable by using stumpage value relatives of the type shown in table 3.

Red oak was chosen as the basis for comparing outputs.

The value relatives describe the predicted stumpage value of various species and qualities in terms of the present value of mature red oak stumpage, log grade 1. Thus, by multiplying each entry in the output table (table 2) by the corresponding entry in the value-relative table (table 3) and summing the products, the output can be converted to "present-value equivalent units" (or "value units", for short) defined in terms of red oak, log grade 1. The result in the case of the stand described in table 2 is 9,345. This means that the predicted value of the output of this stand

Table 2.--Net output per acre for a managed cove hardwood stand on Site 1

(Harvest date 1990-99; stand first managed in poletimber stage)

Log grade	Sawtimber									Pulpwood
	Red oak	White oak	Yellow-poplar	Beech	Sugar maple	Black cherry	Ash and basswood	Other hardwoods	White pine	Spruce
	Board-feet									Cords
1	1,260	130	6,290	50	80	--	1,480		--	
2	740	180	3,140	80	50	--	770	4,140*	--	--
3	2,070	610	3,900	300	110	--	1,770		--	
Structural	1,660	360	1,650	210	80	--	770		--	

* Sawtimber, other hardwoods were not separated by log grades.

Table 3.--Discounted stumpage-value relatives for the decade 1990-99

(Value relatives based on present value of red oak sawtimber stumpage, log grade 1)

Log grade	Sawtimber									Pulpwood
	Red oak	White oak	Yellow-poplar	Beech	Sugar maple	Black cherry	Ash and basswood	Other hardwoods	White pine	Spruce
1	0.469	0.500	0.529	0.379	0.529	0.830	0.512		0.684	
2	.271	.301	.325	.241	.331	.385	.289	0.187*	.385	0.040
3	.145	.175	.199	.115	.205	.199	.127		.172	
Structural	.175	.205	.169	.115	.175	.139	.115		--	

* Sawtimber, other hardwoods were not separated by log grades.

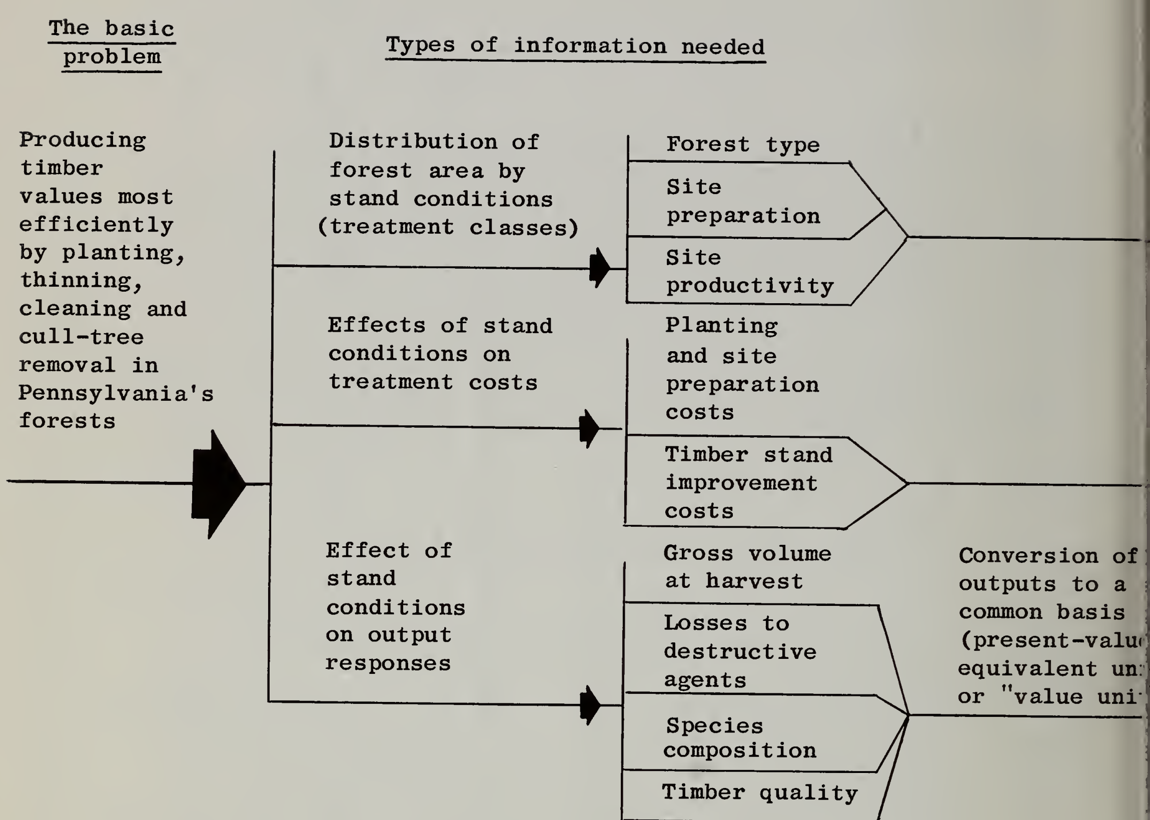
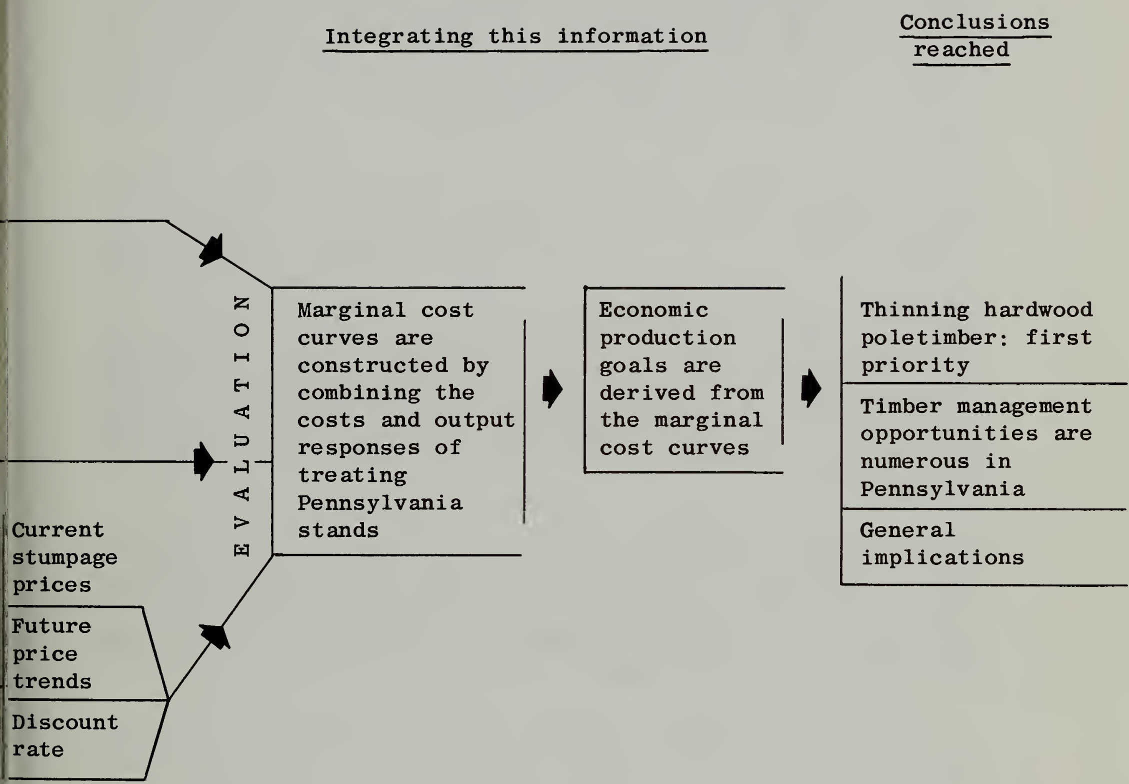


Figure 4.--Steps in the analysis of



nagement opportunities in Pennsylvania

when discounted to the present is equal to the present value of 9,345 board-feet of mature red oak sawtimber stumpage, log grade 1.

Numerous such conversions were carried out. A table similar to table 3 was prepared for each of a series of 10-year periods ranging from the present to the year 2049. Three types of information were used: current stumpage values by product, species, and log grade; estimates of future stumpage-price trends; and a discount rate of 3 percent. The current stumpage values were used to define present value relationships among products, species, and log grades; the price trends gave predictions of these relationships in the future; and the discount rate was used to discount these predicted values back to the present.

The outputs for softwood plantations, unmanaged hardwood stands, and managed hardwood stands were converted to "value units". After we made this conversion, we calculated additional output due to management in hardwood stands for each treatment class by taking the difference between outputs for managed and unmanaged stands. Once this was done, we compiled the data needed to compare timber-management opportunities. These data included estimates of area, treatment cost, and output response for each treatment class specified for planting, for cleaning and cull-tree removal, and for thinning.

Before actually making these comparisons, however, let us consider two questions: How were current stumpage values and future stumpage price trends estimated? And what important assumptions were made in compiling the area, cost, and output-response data?

Current stumpage values.--In order to use available price data most effectively, we estimated current stumpage values by product, species, and log grade in two ways. The value of spruce pulpwood stumpage was the average price paid for such stumpage during 1956 in Pennsylvania and adjoining states.[8] Sawtimber stumpage values were estimated via an indirect procedure, using stumpage-price data for state forest timber sales during 1956 and estimates of price-differences among various log grades and species for delivered logs. These price-differences were obtained from data collected in a regional timber-products-marketing study.[9]

[8]Unpublished data, Northeastern Forest Experiment Station.

[9]Northeastern Regional Marketing Project NEM-6.

The state forest stumpage-price data were used to estimate stumpage values by log grades for red oak. (The geographic distribution of the red oak type corresponds more closely to state-owned forest land than does the distribution of any other major forest type). Stumpage values by log grades for other species were then calculated from the values for red oak by directly applying the price-differences for delivered logs.

Future stumpage-price trends.--Future stumpage-price trends were estimated separately for hardwood sawtimber (using red oak, log grade 1, as the base), for white pine sawtimber, and for spruce pulpwood. We made these estimates assuming that there would be a perfectly elastic demand for timber produced in Pennsylvania because the state produces only a small part of the national output of each of these products and is not likely to greatly increase its share of national output. The problem was thus one of estimating future levels of the demand curves for various kinds of Pennsylvania-produced timber.

Price estimates for hardwood and white pine sawtimber were based upon a constant-dollar projection of the all-species wholesale lumber price index issued by the Bureau of Labor Statistics. This projection was made for 1975 and 2010, using the following relationship:[10]

$$Y = 23.8 - \underset{(.073)}{.105X_1} + \underset{(.167)}{.700X_2} + \underset{(.177)}{.400X_3}$$

$R = .80$ over the period 1915-56

where Y = Bureau of Labor Statistics all-species wholesale lumber price index in 1926 dollars

X_1 = Per capita annual lumber consumption in board-feet

X_2 = Per capita annual construction expenditures in 1926 dollars

X_3 = An index of lumber manufacturing cost constructed by Div. of Forest Economics Research, Washington Office, U. S. Forest Service (1926 = 100).

Once values of the lumber-price index were estimated for 1975 and 2010, we were able to obtain stumpage prices for these dates for each of three qualities of white pine

[10] Unpublished manuscript by I. Irving Holland, U. S. Forest Service, Washington, 1957.

sawtimber stumpage and for red oak, log grade 1. We did this by estimating appropriate ratios of stumpage price/lumber-price index and then making calculations of the following type:

$$\text{Stumpage price} = \begin{matrix}\text{Lumber}\\ \text{price}\\ \text{index}\end{matrix} \times \left(\frac{\text{Stumpage price}}{\text{Lumber price index}} \right)$$

Finally, we extended the resulting stumpage prices over the entire time period considered. Linear projection based on three points--1955, 1975, and 2010--was used, even though it might be argued that some sort of long-term equilibrium will evolve with increasingly intensive forest management. However, there were not enough data available for any reasonable estimate of future curvilinear price trend.

Applicable studies of pulpwood prices are not available. Therefore future prices for spruce pulpwood stumpage were based upon estimates we made by using linear projection of past prices (1900-34 data from Steer, 1938; 1937-55 data from U.S. Forest Service, 1957). The logic of the estimates is as follows: the likely users of spruce pulpwood produced in Pennsylvania are pulpmills within the state and in western New York. These mills now obtain virtually all of their spruce pulpwood from eastern Canada, and will probably do so in the future. Therefore, with planting on any foreseeable scale, Pennsylvania will still remain a relatively minor source of spruce pulpwood. Thus a price high enough to buy any spruce pulpwood in Pennsylvania will probably buy most of it available. This is because stumpage is sold primarily by landowners who have little interest in their forest holdings; and once price is high enough to attract some of these owners, it will probably attract nearly all of them.

Yet at some point any further increase in the quantity of pulpwood sought will require cutting stands being held for aesthetic or ornamental purposes. And at this point, even sharp price increases will buy very little more pulpwood. Therefore the pulpmills will probably try to set their prices just high enough to obtain all the spruce stumpage available from willing sellers. Though drastic changes in this price are unlikely, a gradual rise in real price will probably occur. This gradual rise, as indicated by past trends, will keep local suppliers of pulpwood happy. And it will serve as insurance against any temporary shortage of spruce pulpwood from Canada.

So much for the principal features of the current stumpage values and future stumpage-price trends used in deriving stumpage-value relatives.

SEVERAL MAJOR ASSUMPTIONS

In compiling the data, we could not include all of the costs and outputs associated with management. One such cost was that of persuading private owners of forest land to adopt forestry practices. No estimate of this cost was made because at present we have no basis for developing such an estimate. Consequently, if private owners do not voluntarily adopt those practices profitable to them, costs of growing additional timber on private land have been underestimated. However, if costs of persuading owners to adopt certain practices are roughly the same for all practices, then the cost estimates will still help determine the best division of funds among practices on private forest land.

Then too, only the cost of initial treatment and the effects of management on the final harvest were included in the analysis. For example, in evaluating management that begins with planting or cleaning and cull-tree removal, we ignored both the costs and the immediate outputs of subsequent thinnings. Costs of early thinnings will at first exceed the value of the timber removed, but later thinnings which remove more valuable trees will result in net incomes. These intermediate costs and returns will probably just about offset each other when discounted to present values; thus they were excluded from this analysis.

When management begins with thinning in poletimber stands, however, merchantable timber may be removed in thinnings right from the start. Therefore, values derived from these thinnings must be recognized. Ideally, each thinning should be considered separately. This would involve specifying for each thinning the cost, the volume of merchantable timber removed, and the species composition and log-grade breakdown for this timber. Yet, research foresters with whom we discussed this part of the analysis were unable to specify confidently the volumes they would remove in particular thinnings although they could give some idea of the volume to be removed in all thinnings taken together. Specification of species and log-grade breakdowns for sawtimber removed in thinnings also proved infeasible.

For these reasons, we used the following procedure: (1) The first thinning was treated as if no merchantable timber were removed, (2) outputs in all thinnings taken together were treated as if they had occurred at the final harvest, (3) thinning outputs were assumed to have the same species composition and log-grade breakdowns as the final harvest, and (4) costs of subsequent thinnings were ignored.

This procedure departs from reality in several ways: (1) some pulpwood will be removed in the first thinning in

many poletimber stands, (2) the time before thinning outputs will be obtained is over-stated, (3) thinning outputs will have poorer species composition and log-grade breakdowns than the final harvest, and (4) subsequent thinnings will be a source of cost, as well as a source of output. However, within practical limits, these departures from reality cancel each other in terms of the cost of producing additional timber through management programs beginning with thinning in poletimber stands; in the first two departures, these costs are overestimated, while in the last two, they are underestimated.

Next let us consider the methods by which these data were brought together to evaluate the Department of Forests and Waters' timber-management opportunities.

Evaluating the Opportunities

The basic data had now been obtained. Treatment classes for planting, for cleaning and cull-tree removal, and for thinning had been specified; area, treatment cost, and output response had been estimated for each class; and all output responses had been converted to "value units". But these data were still not in a form to answer the question: "If the Pennsylvania Department of Forests and Waters were to receive larger appropriations for timber production, how should this money be allocated among various forestry practices?"

To get the most timber for any given amount of money, the last dollar allocated to each set of practices must produce the same increase in output in "value units". In other words, the additional cost of the last thousand "value units" of timber produced by planting on essentially bare land, the additional cost of the last thousand "value units" of timber produced by cleaning and cull-tree removal in hardwood seedling-and-sapling stands, and the additional cost of the last thousand "value units" of timber produced by thinning in hardwood poletimber stands must all be the same. If the additional costs are not the same, then more timber can be produced by switching funds from practices with relatively high cost for the last thousand units to practices with relatively low cost for the last thousand units.

The additional cost of the last thousand units of timber produced through planting, say, will depend on the total amount being produced, since treatment classes with

the lowest costs will be planted first, etc. Therefore, the simplest way to compare the additional costs of the last thousand units produced through each of the three sets of practices, is to construct curves or schedules--one for each set of practices--relating this cost to the quantity of timber being produced. Since the "additional cost of the last thousand units" is known as the "marginal cost", the schedules are known as marginal-cost schedules. Once constructed, these schedules can be used to determine the best allocation of money at various levels of expenditure.

CONSTRUCTING MARGINAL-COST SCHEDULES

Our first step in constructing marginal-cost schedules was to arrange the treatment classes for each practice --planting, cleaning and cull-tree removal, thinning--in increasing cost order. We based this cost order on unit cost of additional output, calculated for each treatment class by dividing the output response (in "value units") into the treatment cost. The resulting unit costs we then arranged from lowest to highest.

Our second step was to construct the total variable cost schedules shown in figures 5, 6, and 7.[11] These schedules relate the total increase in cost for expanded planting programs of various sizes; for example, to the total quantities of additional timber that will result from these programs.

The "graph points" used in constructing the schedules were obtained by calculating the total increase in cost and the total additional output for each of a series of acreages. In the case of planting, there were 45 acreages ranging from zero to 1.1 million acres--the total area in all eleven treatment classes for planting.

In making these calculations, we used the treatment-class area and output-response estimates directly, while we used the treatment-cost estimates after applying a risk allowance of 10 percent of other costs. This risk allowance took account of uncertainty of future markets and probable losses to wind, animals, ice storms and other unpredictable destructive agents.

Our third and final step was to statistically fit marginal-cost schedules to values obtained by calculating the marginal cost between successive points on the total variable-cost schedules:

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[11]Administrative costs were assumed fixed.

$$\text{Marginal cost} = \frac{\text{Change in total variable cost}}{\text{Associated change in total output}}$$

In the process of carrying out these steps, we discovered that, for each set of forestry practices, a sudden change in cost conditions occurs. This cost change takes place as soon as treatment proceeds beyond site-productivity classes I and II and into site-productivity class III and scrub oak land. Therefore planting, cleaning and cull-tree removal, and thinning were each treated as though they were separate practices on Sites I and II and on Site III and scrub oak land.

The marginal-cost schedules we obtained are as follows:

Planting:

Sites I and II	$Y = 14.106 + 0.043X$ (range of X, 0-1020)
Sites III and scrub oak land	$Y = 83.3178 + 0.0855X^2$ (range of X, 0-60)

Cleaning and cull-tree removal:

Sites I and II	$\log Y = 0.7156 + 0.001293X$ (range of X, 0-720)
Site III	$Y = 205.33$ (range of X, 0-20)

Thinning:

Sites I and II	$\log Y = 0.08605 + 0.0002697X$ (range of X, 0-4910)
Site III	$Y = 84.03$ (range of X, 0-90)

Where X is total additional output in millions of "value units" defined in terms of board-feet of mature red oak sawtimber, log grade 1, and Y is marginal cost per 1,000 "value units" in dollars.

For cleaning and cull-tree removal and for thinning, there is only a single treatment class on Site III. Therefore the marginal costs of treatment on Site III are equal to the unit costs of additional output on these treatment classes. These unit costs were calculated in arranging the treatment classes in increasing cost order.

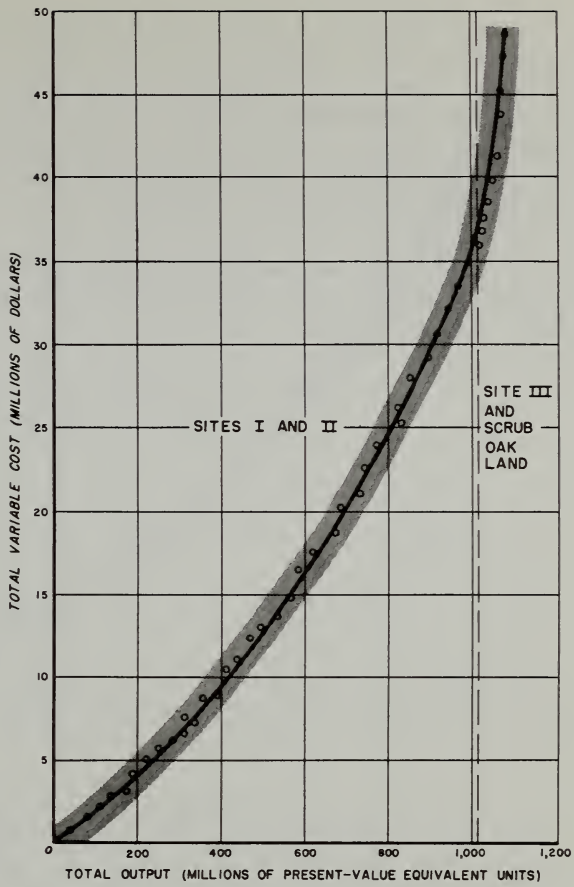

Figure 5.--*Total variable-cost schedule for planting.*

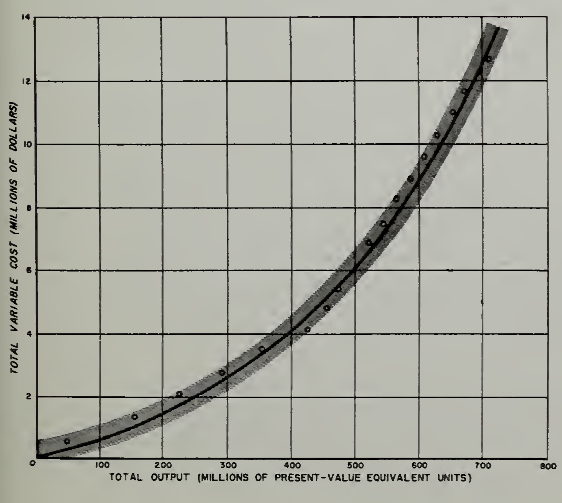

Figure 6.--*Total variable-cost schedule for cleaning and cull tree removal on Sites I and II.*

Figure 8 shows the marginal-cost schedules.[12] The striking fact brought out by figure 5 is that the marginal cost of additional timber produced by means of thinning in hardwood-poletimber stands is a great deal lower than the marginal costs of the other two practices. This situation is caused mainly by the large areas in the more productive treatment classes for thinning.

Now to use these marginal-cost schedules to determine economic goals that are useful in comparing timber-management opportunities.

DETERMINING ECONOMIC GOALS FOR CURRENT MANAGEMENT OPPORTUNITIES

The economic goals derived in this study set forth the pattern of expenditure on planting, cleaning and cull-tree removal, and thinning that will produce additional timber at minimum cost. To best illustrate this pattern, three types of information are useful: (1) a priority scale for all the treatment classes taken together; (2) a guide to the proportion of funds to be spent on each set of forestry practices at various levels of expenditure: and (3) a list of the treatment classes to be planted, thinned, etc., at each of these levels of expenditure.

The priority scale was established by combining the priority scales for planting, for cleaning and cull-tree removal, and for thinning. These separate priority scales had been determined in constructing the marginal-cost schedules.

Estimating the proportions of funds to be spent on each set of forestry practices involved four steps. In the first, each of a series of eleven evenly-spaced values on the dollar axis in figure 8 was equated with each of the marginal-cost schedules as illustrated. The result was an estimate of the "optimum" outputs through each set of forestry practices at each of these value-levels. In the second step, the expenditures required to produce these optimum outputs were estimated from the total variable-cost schedules (fig. 5, 6, and 7). In the third step, these expenditures for planting, for cleaning and cull-tree removal, and for thinning, were added together at each value-level. And in the fourth, each expenditure for planting, thinning, etc. was expressed as a percentage of the total expenditures determined in the third step.

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[12] Only the marginal-cost schedules for Sites I and II appear in figure 8. The costs (on an output basis) of planting, cleaning, and cull-tree removal, and thinning on Site III and scrub oak land are so high that to use these areas to produce least-cost timber seems extremely unwise.

Figure 7.--*Total variable-cost schedule for thinning on Sites I and II.*

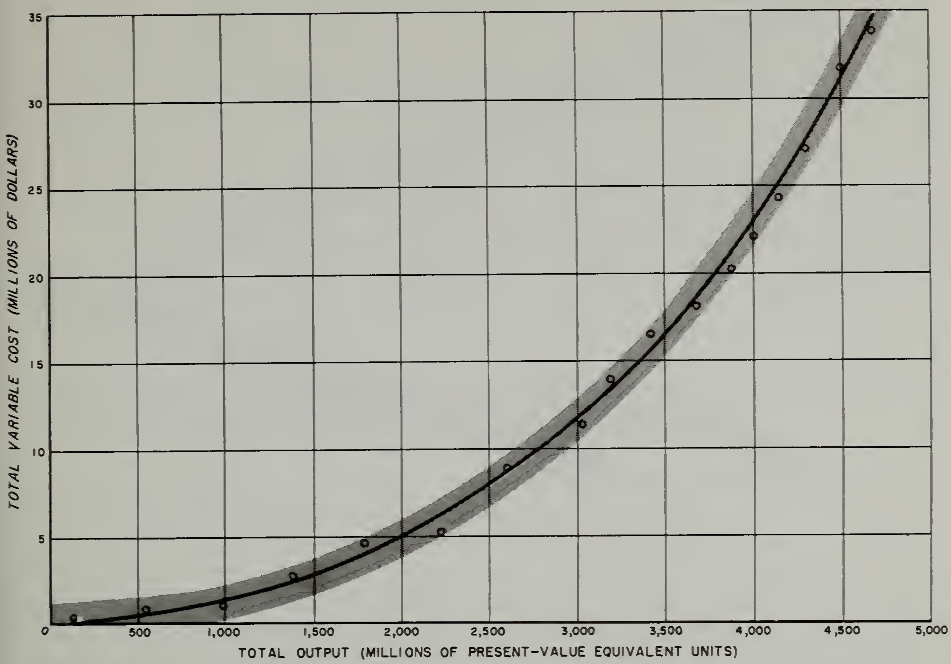
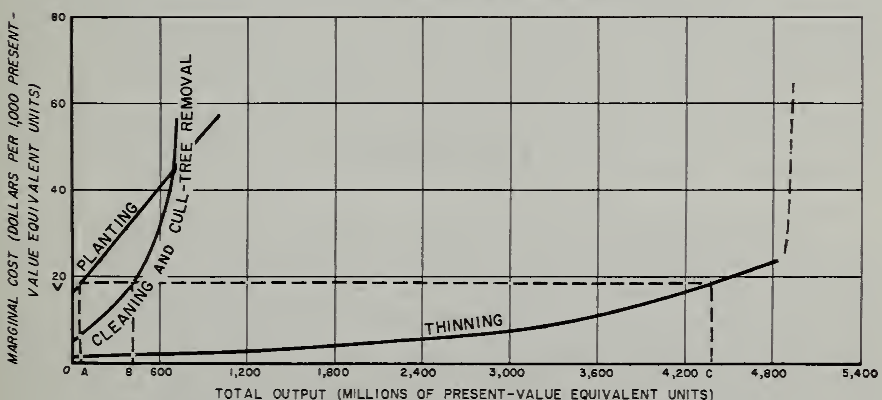


Figure 8.--*Marginal-cost schedules for three ways of increasing stumpage production in Pennsylvania (Sites I and II).*



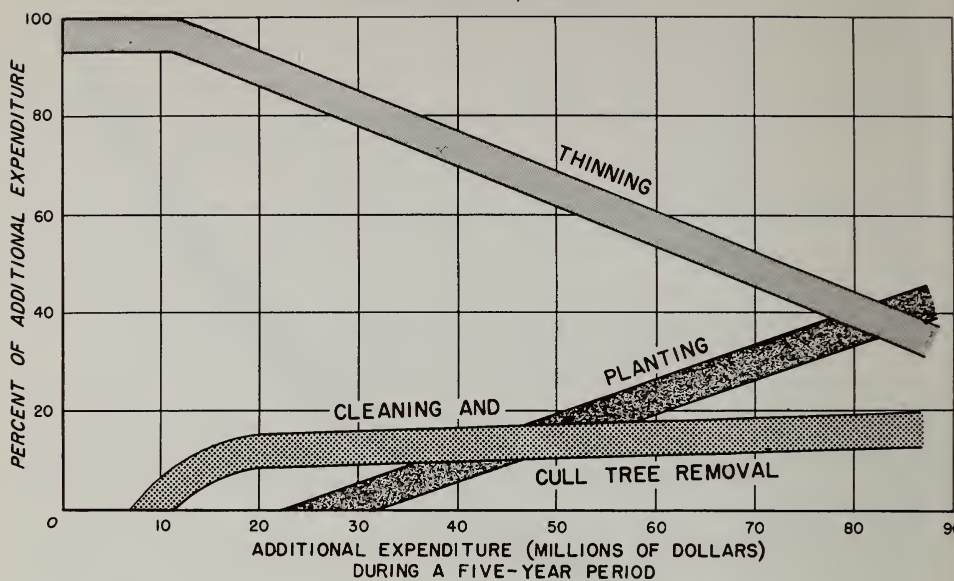
V = one of eleven value-levels arbitrarily selected in determining economic goals for current management opportunities.

A = optimum output at value-level "V" for management programs beginning with planting softwoods on bare and lightly stocked forest land.

B = optimum output at value-level "V" for management programs beginning with cleaning and cull-tree removal in hardwood seedling-and-sapling stands.

C = optimum output at value-level "V" for management programs beginning with thinning in hardwood poletimber stands.

Figure 9.--*Optimum allocation of funds at alternative levels of additional expenditure.*



Finally, the treatment classes to be planted, thinned, etc., at various levels of expenditures were identified. To do this, we compared the optimum outputs at each value-level with cumulative output ranges for the treatment classes for planting, thinning, etc., arranged in increasing cost order.

So much for the procedure used to determine economic goals for current management opportunities. Now to the goals themselves.

Conclusions

The purpose of this study was to compare three types of timber-management opportunities available to the Pennsylvania Department of Forests and Waters. The central question was: How should the Department allocate additional appropriations among these three practices? And the greatest possible increase in timber values with any given increase in available funds was the standard to be used in making the comparisons.

In some instances, of course, considerations of water, wildlife, and recreation values may run counter to conclusions based on production of timber at a minimum cost. For example, in some areas planting open land might result in far greater watershed-protection benefits than would

thinning hardwood poletimber. In such cases the Pennsylvania Department of Forests and Waters would have to weigh these other values in relation to timber production. This analysis of timber-management opportunities should provide a point of departure for such comparisons. But where other values are unaffected, the conclusions reported here can be applied directly.

BEST TIMBER-MANAGEMENT OPPORTUNITIES

Our study showed that timber production could be increased most efficiently by first concentrating effort on thinning in hardwood-poletimber stands (fig. 9, tables 4 and 5). For example, all of a 5 million dollar increase in expenditures during the next 5 years should be devoted to thinning if additional timber is to be produced at minimum cost.

If larger increases in expenditure were possible, funds could be profitably diverted to planting and cleaning and cull-tree removal. This diversion, of course, would have the effect of reducing the proportion of expenditure allocated to thinning. But even for increases in expenditures up to 60 or 70 million dollars, thinning should be emphasized much more strongly than the other practices.

Considerable judgment went into reaching these conclusions. Output responses had to be specified and quantified, future stumpage-price trends had to be estimated, an appropriate interest rate for discounting future values had to be determined, and so forth. Nevertheless, the conclusions can be treated with considerable confidence. They have been tested by changing these basic assumptions and reworking the analysis. The relative ranking of these opportunities and the conclusion that thinning in hardwood poletimber rates first priority remained essentially unchanged.

OTHER TIMBER-MANAGEMENT OPPORTUNITIES

Guides to allocation of funds will be useful to the Pennsylvania Department of Forests and Waters in spending their appropriations to produce timber most efficiently. However, there is another important question: "How much more money should be spent to increase timber production in Pennsylvania?" This is a legislative question for all Pennsylvanians to help answer--and this study may help them answer it.

According to our estimates $78 million--$34 million for thinning, $31 million for planting, and $13 million for cleaning and cull-tree removal--could be invested during the next 5 years with the prospect of receiving more than one

Table 4.--Priorities for timber-management opportunities

Treatment class	Cost per unit of value-response dollars	Class acreage thousand acres
Thinning--northern hardwood-poletimber stands, Site I	4	234
Thinning--cove hardwood-poletimber stands, Site I	4	12
Thinning--northern hardwood-poletimber stands, Site II	5	1,436
Thinning--oak-poletimber stands, Site I	6	47
Cleaning and cull-tree removal--northern hardwood seedling and sapling stands, Site I	7	42
Thinning--cove hardwood-poletimber stands, Site II	8	18
Cleaning and cull-tree removal--northern hardwood seedling-and sapling stands, Site II	9	258
Planting--open land, Site I	11	68
Thinning--oak poletimber stands, Site II	11	1,470
Cleaning and cull-tree removal--oak seedling-and-sapling stands, Site I	14	19
Planting--open land, Site II	15	442
Planting--forest land less than 10 percent stocked, aerial site preparation, Site I	20	14
Planting--forest land less than 10 percent stocked, ground site preparation, Site I	24	33
Planting--forest land less than 10 percent stocked, aerial site preparation, Site II	28	89
Cleaning and cull-tree removal--oak seedling-and-sapling stands, Site II	28	611
Planting--forest land less than 10 percent stocked, ground site preparation, Site II	33	219
Planting--open land, Site III	52	80
Thinning--oak poletimber stands, Site III	76	816
Planting--forest land less than 10 percent stocked, aerial site preparation, Site III	96	16
Planting--forest land less than 10 percent stocked, ground site preparation, Site III	110	39
Cleaning and cull-tree removal--oak seedling-and-sapling stands, Site III	190	340
Planting--scrub oak land, root-rake site preparation	270	40
Planting--scrub oak land, too rocky for root-rake site preparation	470	60

dollar's worth of additional timber for every dollar invested.[13] Our results also indicate that with an investment this large, the forestry practices considered would offer profitable public investment opportunities on all treatment classes on Sites I and II. On the other hand, on Site III and scrub oak land these practices will not return their costs if timber produced is the only value considered.

Thus the opportunities for profitable management of Pennsylvania's forests appear to be very promising, if forest managers give careful consideration to the practices used and the sites on which they are applied.

OTHER IMPLICATIONS

There are also several broad implications that apply to any comparison of timber-management opportunities. But first, what are the relative strengths and weaknesses of the various kinds of data used? And what types of studies are required to repair the weaknesses?

We used four types of information in the study: these were estimates of area, cost, output response for each of a series of treatment classes, and a system for converting the output response of various stands to a common basis. Of these four estimates, the first two are doubtless the stronger. Accurate prediction of output responses requires long-term studies, and any system for converting outputs to a common basis forces us to speculate on the future.

Long-term studies of the response of stands to specific management measures would be particularly helpful in strengthening future studies of this type. "Compartment studies" being carried out on experimental forests operated by the Forest Service will eventually be of major assistance. But practical decision-making can not be deferred until these studies are completed. Decisions must be made no matter how incomplete the information available at the time. For that reason, in this study we attempted to anticipate the results of long-term studies by using the judgment of experienced foresters.

[13] These goals were determined by first setting each of the marginal-cost schedules in figure 8 equal to $54 to estimate optimum outputs, and then reading the expenditures necessary to produce these outputs from the total variable-cost schedules in figures 5, 6, and 7. $54 per 1,000 board feet is the current value of red oak, log grade 1, the species and quality used as the base in converting outputs to a common basis.

Table 5.--Treatment classes to be managed at alternative levels of additional expenditure

Additional expenditure: Annually	Additional expenditure: During 5-year period	Planted	Cleaned and cull trees removed	Thinned
Million dollars				
0.5	2.5	None	None	Northern hardwood-poletimber stands on Site I Cove hardwood-poletimber stands on Site I
2	10	None	Northern hardwood seedling-and-sapling stands on Site I	Northern hardwood-poletimber stands on Sites I and II Cove hardwood-poletimber stands on Site I
5	25	None	Northern hardwood seedling-and-sapling stands on Sites I and II	Northern hardwood-poletimber stands on Sites I and II Cove hardwood-poletimber stands on Sites I and II Oak poletimber stands on Site I
10	50	Bare land, Sites I and II	Northern hardwood seedling-and-sapling stands on Sites I and II Oak seedling-and-sapling stands on Site I	As above
15	75	Bare land, Sites I and II Forest land less than 10 percent stocked, in holdings large enough for aerial site-preparation treatment, on Sites I and II Forest land less than 10 percent stocked, in holdings suitable only for site-preparation by ground methods (i.e. too small for aerial treatment) on Site I	Northern hardwood seedling-and-sapling stands on Sites I and II Oak seedling-and-sapling stands on Sites I and II	Northern hardwood-poletimber stands on Sites I and II Cove hardwood-poletimber stands on Sites I and II Oak poletimber stands on Sites I and II
15.7	78.6	Bare land, Sites I and II Forest land less than 10 percent stocked, both aerial and ground site-preparation treatments, on Sites I and II	As above	As above

Now to broader implications.

The first implication for any comparison of timber-management opportunities is that the investment period between initial management and final harvest greatly influences the costs of increasing output--and the length of investment period differs greatly between practices. For example, timber output from a hardwood stand can be increased considerably more if management is begun early in the development of the stand than if it is begun late. Yet differences in costs go the other way when management programs begun in seedling-and-sapling stands are compared with those begun in poletimber stands, for particular forest types and site classes. In every case the management program that starts with thinning in poletimber stands produces timber more cheaply (table 4). The shorter investment period more than offsets the smaller change in output, even with a relatively low 3-percent discount rate. Naturally the investment period is particularly important now with little timber under management and there is the question of which stands to work in first. When (and if) most stands are being managed,

it will not matter so much: today, the importance of the investment period can not be overemphasized.

The second and perhaps most striking implication is that there is a tremendous range in the costs of producing additional timber values. To take the extremes: The cost of producing additional timber values by planting scrub-oak land is more than 75 *times* the cost of producing additional timber values by thinning in hardwood-poletimber stands containing valuable species and located on productive sites (table 4). To produce timber efficiently, managers must keep an eye on costs in relation to output.

The third implication is that per-acre output differences are a much more important source of this range in output costs than are per-acre cost differences. In the case of planting, per-acre costs on the most expensive of 11 treatment classes for planting are $3\frac{1}{2}$ times the costs on the cheapest, while in terms of output-per-acre the most productive and least productive treatment classes differ by a factor of nearly 12.

All of these implications, and particularly the last two, underscore the necessity of appraising timber-management opportunities *in relation to each other,* and for doing it in terms of *cost on an output basis.*

Summary

A study was made to analyze the Pennsylvania Department of Forests and Waters' timber-management opportunities in connection with three sets of forestry practices: (1) planting softwoods on open and lightly stocked forest land; (2) cleaning and cull-tree removal in hardwood seedling-and-sapling stands; and (3) thinning in hardwood-poletimber stands. These opportunities were ranked from best to poorest in terms of the costs of producing more timber. And guides were established to help in determining the best division of funds among these three sets of practices at various levels of expenditure.

The practical conclusions of this study are several. One of the most dramatic is the magnitude of the profitable management opportunities. According to this analysis, dur-

ing the next few years an additional $78,000,000 could be profitably invested on these three sets of forestry practices in Pennsylvania's forests.

But even more important from the standpoint of the Department of Forests and Waters are the conclusions about how any increases in funds should be spent to achieve the greatest benefit in terms of timber values. This study indicates that timber production can be increased most efficiently by first concentrating on thinning in hardwood-poletimber stands, rather than on other practices that are frequently recommended.

The study showed a tremendous range in the costs of producing additional timber in Pennsylvania. Thus the results demonstrate the importance of evaluating timber-management opportunities *in relation to each other* and also in terms of *cost on an output basis.*

This study also illustrates the four steps necessary for any comparison of forestry opportunities. The first of these steps is to *state the objective* precisely. Is it to produce more timber at minimum cost? Is it to obtain the greatest increase in water values possible for a given expenditure? Just exactly what is it? The second step is to *identify the opportunities* to be compared. What are the alternate courses of action, the various methods that could be used to achieve the stated objective? The third step is to *specify the basis on which comparisons are to be made.* What benefits and costs are to be recognized? What procedure is to be used in comparing them? The fourth step is to *make the comparisons.*

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